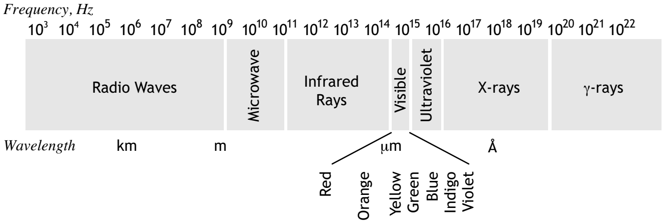
Properties of Light
Answers and Explanations

1. C

There are not precise boundaries between the types of electromagnetic radiation. Radio waves are the longest wavelength type with wavelengths greater than approximately 1 meter ($f < 100\text{MHz}$). With higher frequency and shorter wavelengths, microwaves are sometimes referred to as short-wavelength radio waves ($30\text{cm} > \lambda > 1\text{mm}$). Above microwaves on the spectrum, infrared radiation consists of wavelengths between 1mm up to the longest wavelengths of visible light (about $0.7\mu\text{m}$). Visible light represents the narrow band in the spectrum ($0.7\mu\text{m} > \lambda > 0.4\mu\text{m}$) that the human eye can detect. Above visible light, with ever shorter wavelength and higher frequency, are ultraviolet light, x-rays, and gamma rays.



2. B

Both interference of light and polarization can be explained using a wave approach to electromagnetic radiation, the photoelectric effect is only explicable through quantum theory. In the photoelectric effect, electrons are dislodged from a metal surface only by the impingement of light that has reached or exceeded a threshold frequency. Below that threshold, no electrons are emitted from the material, regardless of the light intensity or the length of time of exposure to the light. To explain these results Einstein proposed that a beam of light is not a wave propagating through space, but rather a collection of discrete wave packets (photons).

3. C

Electromagnetic waves are transverse. Sound waves are longitudinal. Being transverse, electromagnetic waves may be polarized. In a transverse wave, the direction of the oscillation is perpendicular to the direction of motion of the wave. With a transverse wave, a principle of selection may apply with regard to the geometric orientation of the oscillation. In other words, transverse waves may be polarized, longitudinal waves may not.

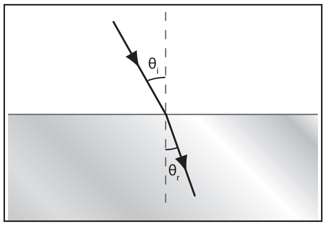
With regard to choice III, both sound waves and electromagnetic waves carry energy, so that property does not distinguish the two types of waves.

4. A

When a light ray travels between media, as it enters the new substance, the light ray is bent or refracted. According to Snell's Law, the product of the index of refraction in the first medium and the sine of the angle of incidence equals the product of the index of refraction in the second medium and the sine of the angle of refraction.

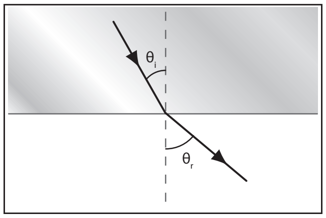
$$n_1 \sin \theta_i = n_2 \sin \theta_r$$

Consequently, light moving from a lower index of refraction medium to a higher index of refraction medium will bend towards the normal.



5. D

Light moving from a higher index of refraction medium to a lower index of refraction medium will bend away from the normal.



6. D

Because the speed of a wave is the product of the wavelength and frequency, you can divide either wavelength or frequency into the wave speed to get the other. The speed of light in air is very close to the speed of light in a vacuum, so we can use **c** here.

$$\lambda = 1.5\ \text{Å} = 1.5 \times 10^{-10}\ \text{m}$$

$$f = \frac{c}{\lambda}$$

$$f = \frac{3 \times 10^{8}\ \text{m/s}}{1.5 \times 10^{-10}\ \text{m}} = 2 \times 10^{18}\ \text{s}^{-1}$$

7. A

Using the dimensionless quantity 'cycle' we say that the wavelength of a harmonic wave tells us the 'meters per cycle', how much spatial distance is involved in a complete cycle. The wave number is the reciprocal of the wavelength. In other words, wave number tells you the number of waves per unit distance, the number of 'cycles per meter.'

The question asks us to identify the type of electromagnetic wave which has a wave number of 1700 cm^{-1}. To determine this corresponds to the infrared spectrum one strategy would be to take the reciprocal of 1700 cm^{-1}, convert from cm to nm, and we would determine a wavelength of approximately 6000 nm. This is longer than visible light, which has a wavelength up to 700 nm. Infrared is the only choice. (Infrared radiation extends from the nominal red edge of the visible spectrum at 700 nanometers (nm) to 1 millimeter (mm)).

However, it is much easier to answer this question quickly if you recognize that this value, 1700 cm^{-1}, is right in the middle of the abscissa of the typical IR spectrograph. In infrared (IR) spectrography the range of incident IR frequencies is designated using wave numbers demarcated using cm^{-1}. A large peak at 1700 cm^{-1} represents the characteristic IR absorption of the stretching vibration of the carbonyl group.

8. B

The index of refraction of a medium is defined as the ratio of the speed of light in a vacuum to the speed of light in the medium.

$$n = \frac{c}{v}$$

To determine the speed of light in a particular medium, divide the speed of light by the index of refraction.

$$v = \frac{c}{n}$$

$$v = \frac{3.0 \times 10^{8}\ \text{m/s}}{1.5}$$

$$v = 2.0 \times 10^{8}\ \text{m/s}$$

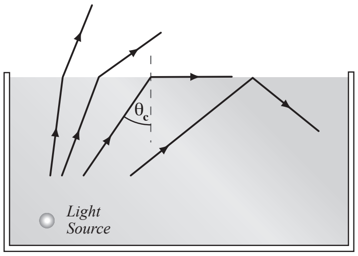
9. A

The speed of light within a medium is inversely proportional to its index of refraction. The greater the index of refraction the slower the medium. Because the frequency of a light ray is constant between media, it follows that the wavelength of the light must change. If speed slows but frequency is the same, the wavelength must now be shorter. In other words, wavelength and speed are directly proportional between media. Wavelength and index of refraction are inversely proportional.

$$\frac{\lambda_2}{\lambda_1} = \frac{v_2}{v_1} \qquad \frac{\lambda_2}{\lambda_1} = \frac{n_1}{n_2}$$

10. A

Light moving at an angle from a higher index of refraction medium to a lower index of refraction medium bends away from the normal. According to Snell's Law, in such cases where $n_1 > n_2$, there is an angle of incidence that corresponds to a 90° angle of refraction. From this angle of incidence, the refracted ray is predicted to move parallel to the interface between the two media. This angle is called the critical angle, θ_c. Light impinging at an angle of incidence greater than the critical angle will not be refracted but internally reflected at the interface. (The sine of the critical angle is simply the ratio n_2/n_1 because sin90° = 1).



$$\sin \theta_c = \frac{n_2}{n_1}$$

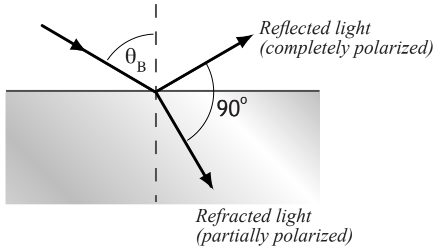
$$(n_1 > n_2)$$

Most of the light entering the front facet of a gem cut diamond undergoes internal reflection off the diamond-air boundary of the back facet. Diamond has a very high refractive index, $n = 2.4$. Because its index of refraction is so high, the critical angle (above which internal reflection occurs) is very low.

11. B

When light is incident at Brewster's angle the *reflected* light will be completely polarized.

$$\tan \theta_B = \frac{n_2}{n_1}$$



The *refracted* light will be partially polarized.

12. B

Infrared radiation is emitted or absorbed by molecules when they change their rotational-vibrational movements. The various stretching, scissoring, wagging, and twisting frequencies associated with bonded atoms vibrating as quantum oscillators within molecules overlap with the frequencies of infrared radiation. Infrared spectroscopy examines absorption of infrared radiation as a method for chemical analysis.

13. C

Refraction occurs as the light enters the crown glass, but given that the light is incident perpendicular to the glass, there is no alteration in the direction of the light ray. The angle of incidence is zero, and the angle of refraction will also be zero. However, the speed of the light will decrease. Because the frequency of a light ray is constant between media, it follows that the wavelength of the light must decrease.

14. A

If plane polarized light passes through a chiral media, for example a solution of the pure isomeric form of a chiral molecule, the plane of polarization of the incident light will be rotated. This is called circular birefringence. This is a major topic within stereochemistry for both organic compounds and coordination complexes.

15. D

Light striking the glass-air interface at a 45° angle is internally reflected. 45° is greater than the critical angle for a crown glass-air interface. Remember that light moving from a high index of refraction medium to a low index medium bends away from the normal. However, light can only bend 90° before it's traveling along the interface, and the critical angle at which this occurs, and beyond which reflection occurs, will be lower, the greater the difference between the indices of refraction of the two media.

$$\sin \theta_c = \frac{n_2}{n_1} \qquad (n_1 > n_2)$$

To use mental math for this problem, remember that the sine of 45° is 0.71, while the n_2 / n_1 in the problem would be 1.0/1.5 or 0.67, so 45° is above the critical angle.

16. D

As the passage describes, dispersion of visible light by a prism occurs because the index of refraction varies somewhat with the frequency of the light. The color of visible light is determined by its frequency.

17. B

According to Snell's Law, the product of the index of refraction in the first medium and the sine of the angle of incidence equals the product of the index of refraction in the second medium and the sine of the angle of refraction. Moving from a lower to a higher index of refraction causes the ray to bend towards the normal.

$$n_1 \sin \theta_i = n_2 \sin \theta_r$$

$$(1.0)(\sin 45°) = (1.5)(\sin \theta_r)$$

$$\sin \theta_r = \frac{(1.0)(0.71)}{(1.5)}$$

$$\sin \theta_r \sim 0.5$$

$$\theta_r \sim 30°$$

18. A

The passage describes how in glass there is increasing refractive index with increasing frequency of light. According to Snell's Law, the greater the index of refraction of the new medium, the smaller the angle of refraction will be. This means that higher frequency light in glass will bend slightly more towards the normal (the line perpendicular to the interface) when moving from air to glass.

Note that both choices **B** and **D** are true statements, but neither answers the question.

19. D

The first thing we should do is convert our wavelength into SI units.

$$600 \text{ nm} = 6.0 \times 10^{-7} \text{ m}$$

The speed of a wave is the product of the wavelength and frequency. You divide wavelength into the wave speed to get the frequency. The speed of light in air is very close to the speed of light in a vacuum, so we can use **c** here.

$$\lambda = 6.0 \times 10^{-7} \text{ m}$$

$$f = \frac{c}{\lambda}$$

$$f = \frac{3 \times 10^{8} \text{ m/s}}{6.0 \times 10^{-7} \text{ m}} = 5.0 \times 10^{14} \text{ s}^{-1} = 500 \text{ THz}$$